An attract-and-kill system to control *Carpophilus* spp. in Australian stone fruit orchards

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Abstract

During two growing seasons, the use of an attract-and-kill system for control of *Carpophilus* spp. (Coleoptera: Nitidulidae) and the effective range or drawing power of the attract-and-kill stations were examined in stone fruit orchards in the Goulburn Valley, northern Victoria, Australia. Three attract-and-kill stations, baited with synthetic aggregation pheromone plus co-attractant, were placed about 50 m apart in the upwind corner of each treated block 5–6 weeks before the fruit began to ripen. Large numbers of *Carpophilus* spp. were caught in the attract-and-kill stations immediately after placement. By the time fruit had ripened, the number of *Carpophilus* spp. caught had decreased greatly. Fruit damage caused by *Carpophilus* spp. in treated blocks, especially in 2000–2001 season, was almost zero (0.1% and 0.6%) in trees and on the ground, respectively, whereas the damage levels in control blocks were 5.2% and 19.9% in trees and on the ground, respectively. This study indicates that excellent protection of ripening stone fruit may be achieved by using attract-and kill-stations.

Introduction

Dried fruit or sap beetles in the genus *Carpophilus* (Coleoptera: Nitidulidae), primarily *Carpophilus davidsoni* Dobson, *C. mutilatus* Erichson, and *C. hemipterus* (L), are the most economically damaging pests of ripening fruit in southern Australia (James et al., 1995, 1996, 1997). The importance of *Carpophilus* spp. in stone fruit production has increased considerably in recent years. *Carpophilus* spp. are attracted to ripening stone fruit and penetrate near the stem end. This is followed by rapid fruit breakdown (Hely et al., 1982), which can result in substantial fruit losses (James et al., 1993, 1997). Growers have reported annual losses of up to 30% of the crop (Hossain et al., 2000). *Carpophilus* spp. also plays an important role in transferring the spores of brown rot (*Monilinia* spp.), initiating the disease in apricots and peaches (Kable, 1969).

No pesticides were registered to control *Carpophilus* spp. on stone fruit in Australia when our project started in the 1999/2000 season. The use of broad-spectrum sprays applied against other pests, such as oriental fruit moth (*Grapholita molesta*), had a suppression effect on secondary pests such as *Carpophilus* spp. Global concern over ground-water pollution and insecticide resistance in certain crop systems have increased the pressure to rethink insecticide use (Epstein et al., 2000). Methods for managing major pests of stone fruit in Australia, such as *G. molesta*, have shifted toward mating disruption with pheromones and away from the use of broad-spectrum insecticides. Populations of *Carpophilus* spp., freed from suppression by pesticides earlier in the fruit season, develop very large populations close to ripening of the crop. Growers are often tempted to apply pesticides inside the withholding period in order to save the crop. This may cause excessive residues to be detected in their fruit. *Carpophilus* spp. abundance varies considerably from year to year and within seasons in Australian stone fruit orchards, which further complicates management. Abundance is strongly influenced by temperature and rainfall conditions (James et al., 1993, 1997).

The smell from ripening or fermenting fruit attracts *Carpophilus* spp., and fermenting fig baits and their synthetic chemical odour have been used in traps for beetle monitoring and control in California fig orchards (Warner,

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1961; Smilanick et al., 1978). James et al. (1998) and Hossain et al. (1999) demonstrated that fermented apple juice (FAJ) could be used to monitor *Carpophilus* spp. populations in stone fruit orchards in Australia. However, fruit-based attractants alone are not effective in protecting fruit crops from *Carpophilus* spp. damage; poisoned fermenting-fruit baits were not able to out-compete naturally ripening figs in Californian orchards (Smilanick, 1979).

Identification and synthesis of the male-produced aggregation pheromones of *C. hemipterus* (Bartelt et al., 1990), *C. mutilatus* (Bartelt et al., 1993), and *C. davidsoni* (Bartelt & James, 1994) made even more potent attractants available for *Carpophilus* spp. management. The fact that both sexes respond to the pheromones increases their practical and potential impact on *Carpophilus* spp. populations. Importantly, the effect of *Carpophilus* spp. pheromones is strongly synergized by various food odours, and the use of food scent as a co-attractant with the aggregation pheromone was recommended (Bartelt et al., 1992). Food-type materials that have been used as synergists for *Carpophilus* spp. aggregation pheromone included fig juices (Bartelt et al., 1990, 1992), rotting grapefruit (Blumberg et al., 1993), whole-wheat bread dough (Bartelt, 1997), and blends of synthetic compound typical of yeast fermentation (Bartelt et al., 1992). James et al. (1998) demonstrated that FAJ was a very effective co-attractant for *Carpophilus* spp. in Australia, and that it retained efficacy for at least 2 weeks. Subsequent trials to demonstrate the field activity of these materials (Bartelt et al., 1992, 1994a, 1994b; James et al., 1994, 2000) highlighted the potential of 'semiochemicals' (aggregation pheromone and the co-attractant) for *Carpophilus* spp. management in stone fruit orchards. Thus, there is potential to use pheromone and co-attractant for *Carpophilus* spp. management using attract-and-kill strategies.

James et al. (1996) demonstrated that perimeter-based attract-and-kill trapping (traps hung in perimeter trees) significantly reduced the incidence of *Carpophilus* spp. in ripe fruit in the centre of a 1-ha apricot block. However, there was almost 100% infestation by *Carpophilus* spp. in fruit on the trees in which the traps were hung. To improve control in the perimeter trees, James et al. (2001) used attract-and-kill stations containing decomposing stone fruit as co-attractant plus aggregation pheromones, placed in an open area in the centre of an orchard, instead of perimeter traps. The percentage of damaged fruit (44%) within 200 m of the pheromone source was significantly greater than in trees located further (200–500 m) away from the pheromone source (14%). Reasons cited by James et al. (2001) to explain the apparent failure to protect trees within 200 m of the pheromone source included insufficient close-range stimuli for *Carpophilus* spp. to enter the stations, poor quality of the food resources in the stations, and ineffective poisoning of the attracted *Carpophilus* spp. Timing of deployment of the stations also appears to have been a factor. Damage was already occurring when the stations were deployed. In unreplicated experiments, James et al. (2001) used cordons of suppression traps 5–10 m away from the trees to suppress populations.

The use of high-density trapping systems before fruit starts to ripen is not likely to be economically sustainable. We postulated that a small number of large stations located upwind from the fruit blocks would reduce the cost of labour and materials, and that early deployment of such stations may reduce the *Carpophilus* spp. populations sufficiently to prevent damage to ripening fruit. James et al. (2001), published after we designed our experiments, developed a similar suggestion. The aim of this study was to develop an effective attract-and-kill method for control of *Carpophilus* spp. in stone fruit orchards and to determine the effective range or drawing power of the attract-and-kill stations.

Materials and methods

Experimental sites

The experiments were conducted over two growing seasons in commercial stone fruit orchards in the Goulburn Valley (GV), northern Victoria, Australia. The GV produces both fresh and canning varieties of stone fruit. About 75% of Victorian stone fruit is produced in the GV, with nearly 70% of this being used for processing.

Experimental sites were established with the installation of monitoring traps in eight orchards containing peach (CV Tatura 204) blocks during late December 1999 and continued until early February 2000. Each experimental block of approximately 1 ha contained approximately 360 trees, with 4.5 m spacing between trees and 5 m between rows. All blocks were almost square-shaped and as similar as possible in terms of the tree age (7–12 years), irrigation (micro jet), and tree training (vase shaped). Four blocks were treated with attract-and-kill stations and four were untreated controls. Treatments were randomly allocated to the blocks. In the 1999–2000 fruit season, blocks were sprayed when necessary with parathion-methyl against *Carpophilus* spp. and other pests, especially for infestations of *G. molesta*. Spraying against *G. molesta* finished prior to December. If a spray was required against *Carpophilus* spp., it was applied during late December or early January.

The experimental design was modified in 2000/2001 in response to the results of 1999/2000. In the 2000/2001 season, only six orchard blocks were available for experiments. Attract-and-kill stations were used in three blocks and the remaining three were untreated controls. Unlike in the 1999/2000 season, the treated blocks did not receive any insecticides and just the southern half of each control block received one parathion-methyl spray during late December or early January against *Carpophilus* spp. in response to growers' concerns. Three of the six blocks used in the 2000/2001 season had been previously used as sites in 1999/2000.

Attract-and-kill stations

In the 1999/2000 season, each attract-and-kill station consisted of three polystyrene boxes (48 × 34 × 19 cm) containing ripening peaches as co-attractant. Peaches were sprayed with Fipronil (0.1 g a.i/l) to kill landing *Carpophilus* spp. The co-attractant used in 2000/2001 was ripening peaches plus fermenting peach nectar absorbed into polyacrylamide granules. The latter was used in an effort to increase beetle attraction, particularly immediately after placement when fruit was still fresh. Peaches used in this experiment were from local fruit packers. The polyacrylamide granules containing fermenting peach nectar were placed into a 1-l plastic container and covered with fine-mesh mosquito net secured with a rubber band to prevent *Carpophilus* spp. entry. The container was placed at the bottom of the polystyrene box and covered with fruit. As before, the fruit was sprayed with Fipronil. To improve the wind-assisted movement of pheromone and co-attractant into the treated blocks, the polystyrene boxes were placed on top of an upturned wooden fruit bin (75 cm in height). Six polystyrene boxes, instead of three as in the previous year, were used in each attract-and-kill station. In both seasons, six pheromone septa were used for each station. Pheromone septa were supported over the polystyrene boxes with wooden skewers and shielded from direct sunlight by a paper plate impaled above the pheromone septa (Figure 1). Synthetic aggregation pheromones (5 mg of each of *C. davidsoni*, *C. hemipterus*, and *C. mutilatus* pheromones per septum) were used. Pheromones were appropriately diluted with hexane and stored in a freezer until needed (James et al., 2000). An antioxidant, butylated hydroxytoluene (BHT), was added (500 µl of solvent containing 1% w/v BHT). Pheromone solution (500 µl) was applied to rubber septa (15 mm diameter × 20 mm long, red rubber, Aldrich Chemical Co., Milwaukee, WI, USA) and allowed to dry and then, 500 µl of hexane was applied to improve the pheromone penetration evenly into the septa. Septa were dried in a fume hood for 2 h and stored in a freezer in tightly packed aluminium foil bags. Septa in stations were replaced with new ones every fortnight. A total of 18 septa (270 mg of *Carpophilus* spp. pheromone) were deployed per treated block fortnightly. The co-attractant (fruit, nectar, and granules) was replaced in all attract-and-kill stations weekly.

Three attract-and-kill stations were placed about 50 m apart in the north-west corner of each treated block to maximize the attraction of *Carpophilus* spp. Prevailing winds are generally from the north-west and *Carpophilus* spp. usually fly upwind to odour sources (Bartelt & James, 1994). Attract-and-kill stations were placed 12–15 m away from the orchard trees of each treated block. All *Carpophilus* spp. collected in each attract-and-kill station were estimated weekly. *Carpophilus* spp. numbers from both inside and outside the fruit were counted. All *Carpophilus* spp. were collected from the bottom of the polystyrene boxes and then taken back to the laboratory for counting and identification. A random 500-beetle subsample was counted and identified to species using the keys of Dobson (1954, 1964). This sample was then placed in a graduated cylinder so that the rest of the population could be measured volumetrically. The results were used to ascertain species composition and to estimate the number of all collected beetles.

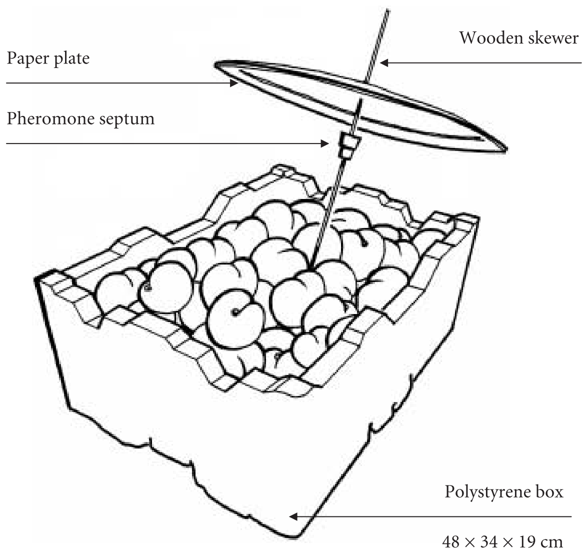

Figure 1 Attract-and-kill station for *Carpophilus* spp. Polystyrene box contains ripening peaches and pheromone septum-supported over the box. The septum was shielded from direct sunlight by a paper plate.

In the 1999/2000 season, attract-and-kill stations were deployed on 7 January and continued up to 2 February 2000. In the following season, the stations were deployed on 8 December, 2000 and continued up to 14 February, 2001.

Fruit damage assessment

Fruit damage assessment was carried out in each of the experimental blocks. In the 1999/2000 season, 500 ripe fruits were randomly picked from three trees around each trap location along the transect of six monitoring traps. A total of 3000 fruits were checked for *Carpophilus* spp. damage from each block and the percentage of damage was calculated. In 2000/2001, 900 fruits were randomly picked from three trees around each trap location along the transect. A total of 5400 fruits were checked for *Carpophilus* spp. damage from each block and the percentage of damage was calculated. In addition, 1000 fruits were randomly picked from five border trees close to each attract-and-kill station. Fallen fruit on the ground (if available) was also checked for any *Carpophilus* spp. damage and the percentage of damage was calculated.

Monitoring of *Carpophilus* spp. populations

A diagonal transect of six traps was established in each experimental block, starting from the north-west corner. The transect was used to improve the ability to detect damage away from the attract-and-kill stations. The first trap was placed approximately 35 m from the attract-and-kill station, with the remaining five traps placed 20 m apart along the same line to monitor the *Carpophilus* spp. flight activity in the orchards. A similar transect was used in the control blocks. The trap positions were numbered consecutively along the transects, with the one nearest the north-west corner of the block being assigned number 1. These traps consisted of Magnet™ funnel traps (Agrisense, Pontypridd, Glamorgan, UK) 23 × 17 cm containing FAJ. Fermented apple juice was prepared by dissolving 1 g of dry yeast in 200 ml of 100% apple juice, which was then absorbed into 10 g of polyacrylamide granules (water crystal, Yates Pty Ltd, New South Wales, Australia). Approximately 200 ml of FAJ was placed in a 300-ml plastic container covered with fine-mesh mosquito net, secured with a rubber band, to prevent *Carpophilus* spp. entering the food attractant. The container with FAJ was placed inside the trap. A small piece of dichlorvos-impregnated plastic strip (1 cm^2) was placed in each trap to kill *Carpophilus* spp. that entered the trap. The FAJ was replaced weekly at the same time as the traps were being serviced. All traps were suspended at about 1.5 m above the ground. Traps were serviced weekly, and beetles were collected and transported to the laboratory for sorting, identifying to species, and counting. Monitoring of experimental blocks started at least 2 weeks before pheromone deployment and continued at least 1 week after the final fruit harvest.

Statistical analysis

In both the 1999/2000 and 2000/2001 seasons, counts of *Carpophilus* spp. in the attract-and-kill stations, assessed on 10 and eight occasions, respectively, were $\log_e$-transformed and analysed by fitting linear mixed models, which use residual maximum likelihood (REML) to estimate variance parameters. Linear mixed models were used because counts of *Carpophilus* spp. were correlated over time. The covariance structure between sampling occasions was described by a power model, which takes into account the fact that correlation decreases as time between assessments increases, and allows for unequally spaced time points. The fixed effect in the model was station; the random effects were initially orchard/station/time. Random effects with zero or negative variance components were removed from the models.

The number of damaged fruit on trees around traps was Poisson-distributed and analysed using generalized linear mixed models with Poisson-error distributions and log-link functions. The fixed effects were spraying/trap and the random effect was orchard. The number of damaged fruit in samples of fruit on the ground was analysed using generalised linear mixed models with binomial-error distributions and logit-link functions. Fixed effect was spraying and random effects were orchard/trap.

Log_e transformed counts of *C. davidsoni* in the monitoring traps were analysed using linear mixed models. The fixed and random effects varied according to the comparisons and contrasts being studied and are detailed in Results. All statistical analyses were performed using GENSTAT 5.42 (Genstat Committee, 2002).

Results

Most of *Carpophilus* spp. (> 98%) caught in monitoring traps and attract-and-kill stations during both seasons were *C. davidsoni.*

Effectiveness of attract-and-kill stations

In the analysis of *Carpophilus* spp. caught in the individual attract-and-kill stations in both 1999/2000 and 2000/2001, orchard, and orchard.station had negative variance components, so were removed from the model. There were no significant differences between stations on orchards in 1999/2000 (d.f. = 6, P>0.67) and 2000/01 (d.f. = 12, P>0.38). We therefore used total number of *Carpophilus* spp. caught in all stations at each site for further analysis.

In the 1999/2000 season, large numbers of *Carpophilus* spp. were caught in the attract-and-kill stations during the first week of the experiment (second week of January) [12,031 ± 5446 (mean ± SE) per treated block], approximately 2 weeks prior to commencement of harvest, but *Carpophilus* spp. numbers dropped by more than 50% during the following week. *Carpophilus* spp. numbers in the stations remained very low (213 ± 76 per treated block on the first week of February) throughout the harvest period (late January to early February) (Figure 2).

In the 2000/2001 season, the mean number of *Carpophilus* spp. caught in the attract-and-kill stations during the first week of the experiment was 232,600 ± 151,209 per treated block, but the population dramatically declined in the

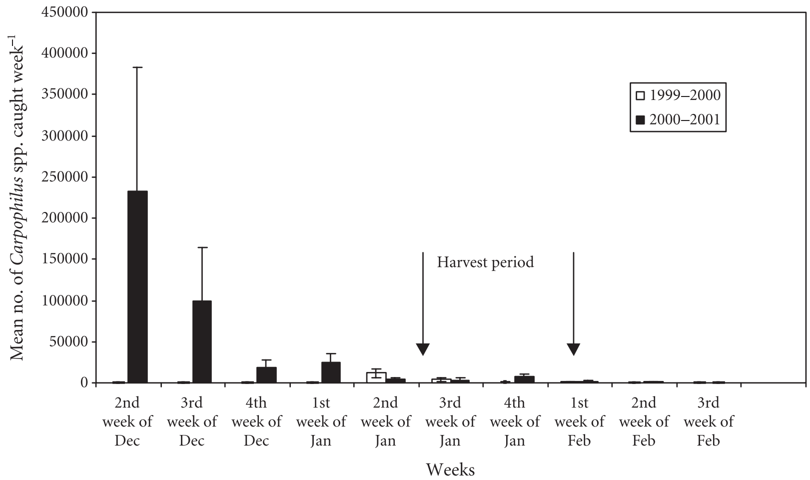

Figure 2 Mean number of *Carpophilus* spp. caught in attract-and-kill stations in 1999/2000 and 2000/2001 seasons. Average was calculated using data from four blocks in 1999/2000 and three blocks in 2000/2001. (Vertical bars indicate SE).

following week to a mean of 99,600 ± 65,632 per treated block. Low numbers of *Carpophilus* spp. (510 ± 75 to 4420 ± 2174 per treated block per week) were caught throughout January and February, including the fruit harvest period (Figure 2).

Fruit damage assessment

In 1999/2000, fruit damage caused by *Carpophilus* spp. in control and treated blocks averaged less than 0.20% (Figure 3). This low level of fruit damage prevented a statistical comparison between treated and control blocks.

In 2000/2001, examination of fruit on trees in the treated blocks during harvest showed *Carpophilus* spp. damage was almost zero (maximum 0.33%). The damage level in control blocks was high (ranging between 2.3 and 9.8%) (Figure 3). Spraying against *Carpophilus* spp. with insecticides significantly lowered the damage level (d.f. = 2, $P<0.001$), compared to that in unsprayed areas in the control blocks (i.e., in Figure 3, the trees near traps 4, 5, and 6, vs. the trees near traps 1, 2, and 3, respectively). Damage in the sprayed area was still much higher than the pheromone-treated blocks. In the unsprayed areas, trees near trap location 3 had significantly lower fruit damage (d.f. = 8, $P<0.01$) than trees in trap locations 1 and 2. Trap 3 was located closest to the sprayed area. There were no significant differences between trap locations 1 and 2 ($P = 0.42$) or between trap locations 4–6 ($P>0.57$).

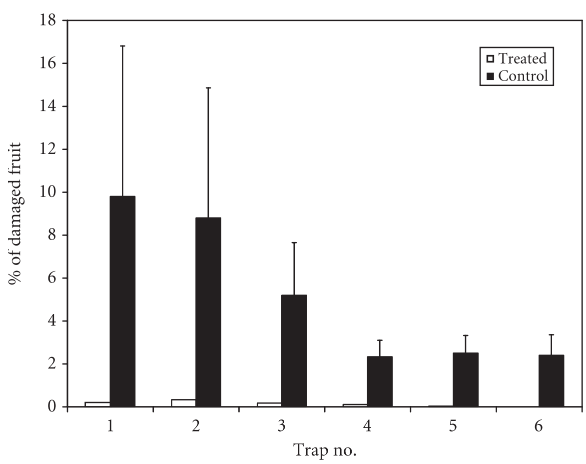

Figure 3 Mean percentage of damaged fruit on tree in control and treated blocks in 2000/2001 season. Trap number indicates the sequence along a transect starting in the north-west corner of each block. Half of the block, positions 4–6, was sprayed against *Carpophilus* spp. Damage results are averages for three blocks. (Vertical bars indicate SE).

Infestation of fruit on the ground in treated blocks was very low, averaging 0.6% (ranged between 0.3 and 1.2%), whereas in control blocks the damage level was high and ranged between 14.6 and 24.7%. The percentage of damaged fruit was significantly higher in the unsprayed areas than in sprayed areas of the control blocks (d.f. = 10, $P<0.01$).

Monitoring of *Carpophilus* spp. populations

In 1999/2000, both control and treated blocks showed similar population trends (Figure 4A). Although the initial populations as indicated by trap catches (before attract-and-kill stations placement) in the treated blocks were generally higher than in the control blocks, there were no significant (d.f. = 21, $P = 0.43$) differences between the initial populations in the blocks (Table 1). High numbers of *C. davidsoni* were recorded in the first week, 145 ± 55 $trap^{-1}week^{-1}$ and 756 ± 297 $trap^{-1}week^{-1}$ in control and treated blocks, respectively. The trap catch dropped sharply in the second week in both control and treated blocks (Figure 4A). There were no significant differences in trap catches

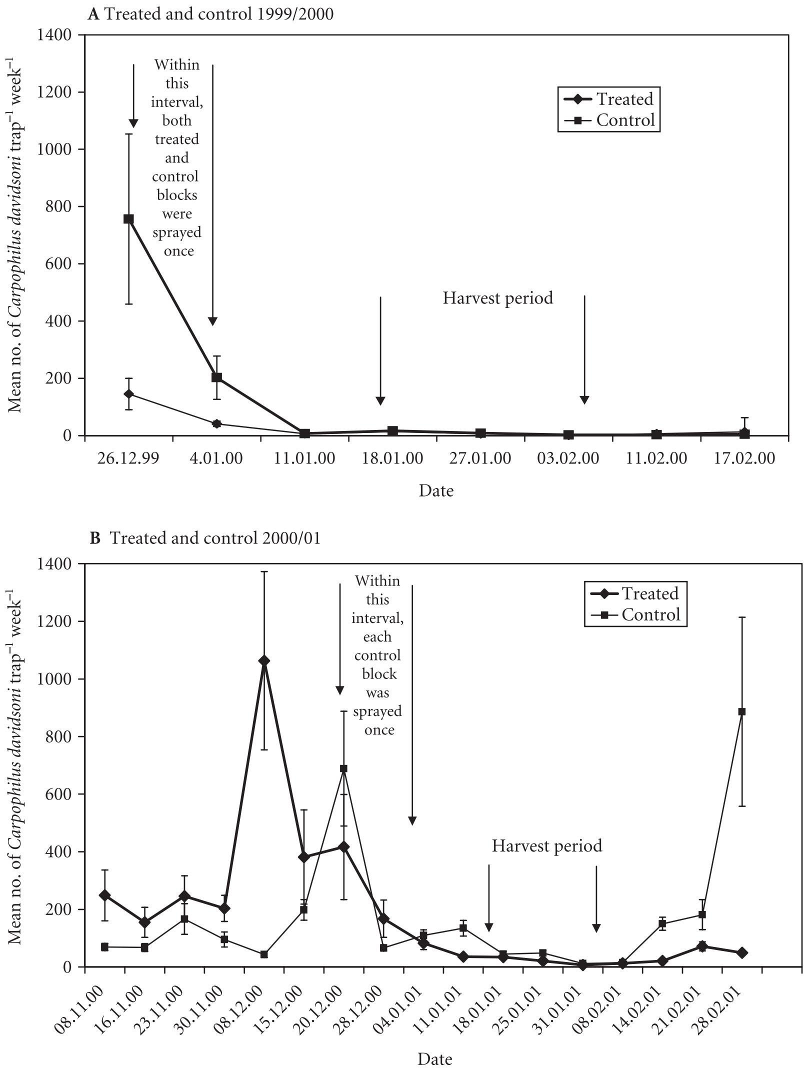

Figure 4 Mean number of *Carpophilus davidsoni* caught in fermented apple juice-baited monitoring traps in control and treated blocks in (A) 1999/2000 and (B) 2000/2001 seasons. Pheromone was deployed in the treated blocks in the 1999/2000 season on 7 January 2000 and in the 2000/2001 season on 8 December 2000. (Vertical bars indicate SE, which is sometimes obscured by data point symbols).

between control and treated blocks (P = 0.74) (Table 2). The fixed effects in these models were pheromone (yes/no) + week (before/after treatment) + trap group (1–3/4–6) + pheromone trap group. The random effect was orchard.

In 2000/2001, the *C. davidsoni* population, as indicated by monitoring traps in the control blocks, increased between 8 and 20 December, then dropped and remained low until after harvest (Figure 4B). The number of *C. davidsoni* caught in the treated blocks was high when the attract-and-kill stations were deployed, but the number dropped immediately afterwards and remained low until well beyond harvest (Figure 4B). The number of *C. davidsoni*

Table 1 Predicted mean $\log_e$-transformed weekly total catches of *Carpophilus davidsoni* in monitoring traps baited with fermented apple juice in traps 1–3, within control and treated blocks in the 1999/2000 season. (Bold face values are back transformed means)

Control 1–3	Treated 1–3	SED	P value
2.09	2.95	1.07	P = 0.43
8.07	**19.01**		

Table 2 Predicted mean $\log_e$ transformed weekly total catches of *Carpophilus davidsoni* in monitoring traps baited with fermented apple juice in control and treated blocks in the 1999/2000 season. (Bold face values are back transformed means)

Control	Treated	SED	P value
2.24	2.61	1.06	P = 0.74
9.40	**13.65**		

Table 3 Predicted mean $\log_e$-transformed weekly catches of *Carpophilus davidsoni* in monitoring traps baited with fermented apple juice in the 2000/01 season. (Values in parenthesis are back-transformed means)

Period	Days	Mean counts		SED	P value
		Pheromone	Control		
Prepheromone	1–31	4.98 (144)	3.80 (44)	1.01	P = 0.24
Postpheromone, pre-spray	38–44	3.94 (51)	5.47 (236)	1.51	P = 0.31
Postspraying	> 58	2.68 (14)	3.64 (38)	0.60	P = 0.11

in control blocks was lower than that in treated blocks up to the first week of December 2000. From the middle of December, the trap catch in the control blocks started to increase (198 ± 36 $trap^{-1}week^{-1}$). Growers were concerned about the population increase, and we negotiated that they would only spray the southern half of the control blocks. The trap catch dropped from 28 December (66 ± 11 $trap^{-1}week^{-1}$), probably as a result of spraying (Figure 4B). The trap catch was slightly higher up to the middle of January. After that, the trap catch trend in both control and treated blocks was comparable up to the harvest period, which ended in the first week of February. After harvest, *C. davidsoni* numbers in the control blocks started to increase and reached the highest level on the last sampling date, whereas no postharvest increase was observed in the treated blocks (Figure 4B).

To better understand the variability in the monitoring trap results, we split the season count into three time segments: prepheromone, postpheromone but pre-spray, and postspraying. In none of the periods was there a significant effect of pheromone treatment on monitoring trap results (d.f. = 4, P>0.10) (Table 3). No significant trap position effect was detected prior to placement of attract-and-kill stations or between placement of stations and prespray (d.f. = 18, P>0.07) (Table 4). In this linear mixed model, the fixed effects were pheromone + trap group and the random effects were orchard/date.

Table 4 Predicted mean $\log_e$-transformed catches of *Carpophilus davidsoni* in monitoring traps baited with fermented apple juice in the 2000/2001 season

Trap position	$\log_e$	Back-transformed mean	SED	P value
Prior to placement of attract-and-kill station				
Traps 1–3	4.27	71.59	0.14	P = 0.13
Traps 4–6	4.43	83.85		
Between placement of attract-and-kill station and prespray				
Traps 1–3	4.51	91.01	0.17	P = 0.08
Traps 4–6	4.83	125.46		

Discussion

Orchard experiments in 1999/2000 and 2000/2001 sought to develop a more effective attract-and-kill system to control *Carpophilus* spp. populations during fruit ripening in stone fruit orchards and to determine the drawing power of the attract-and-kill stations. Previous studies from Australia (James et al., 1994) and the United States (Bartelt et al., 1992) indicated that the synthetic aggregation pheromones of *Carpophilus* spp. are more effective early in the season, when flight activity is high but food supplies are low. Yet we were concerned that the cost of implementing an attract-and-kill system would be prohibitive if season-long deployment was used. Timing of pheromone deployment was important to the economics of the technique.

The study indicated that excellent protection of ripening peaches could be achieved, even when *Carpophilus* spp. pressure was high. The system we used relied on the attract-and-kill stations to drastically reduce the *Carpophilus* spp. populations in the orchard before the crop ripened and became susceptible to damage from *Carpophilus* spp. It may also reduce the impact of *Carpophilus* spp. migrating into treated orchards. In 2000/2001 the attract-and-kill stations were deployed about 5–6 weeks before fruit colour change and ripening was expected. Onset of colour change occurs 1–2 weeks before harvesting starts. Damage in the control blocks averaged near 10% at the start of the transect in the north-west corner (near trap positions 1–3). Damage was lower in the parts of the blocks that were sprayed with insecticides (positions 4–6). Monitoring data showed that the trap catch, especially in the sprayed part of the control blocks, dropped dramatically at the end of December. Fruit damage levels were significantly lower, both on trees and the ground in sprayed areas, compared to those in unsprayed areas of the control blocks. Both *Carpophilus* spp. monitoring data and fruit-damage assessment suggested that spraying against *Carpophilus* spp. with insecticide had some impact on population suppression. However, damage levels were not commercially acceptable. Monitoring data also suggested that even after spraying insecticides against *Carpophilus* spp., populations were higher in the sprayed areas of control blocks compared to pheromone-treated blocks. The 1999/2000 experiment was not definitive because overall *Carpophilus* spp. populations were low and consequent damage was low in all blocks. The results were also confounded because of the use of insecticides, especially in late December or early January, to control *Carpophilus* spp. in both treated and control blocks. In this season, the pheromone was deployed approximately 2 weeks prior to commencement of fruit harvest. High numbers of *C. davidsoni* were recorded in the first week of monitoring. The population dropped sharply in the second week in both control and treated blocks (Figure 4A). This drop was not related to the placement of pheromone in the treated blocks, as the drop occurred before the introduction of pheromone.

Our experiments, especially in the 2000/2001 season, were not designed to compare different timing for deployment of attract-and-kill stations. Insufficient orchards were available to conduct such experiments. One of the main differences between this experiment and that of James et al. (2001) is that in our experiment, the attract-and-kill stations were deployed well before fruit ripening started. Another difference was that we positioned the stations upwind from the orchard, and 12–15 m away from the nearest orchard trees. Unlike James et al. (2001), we did not find any *Carpophilus* spp. damage on trees close to the attract-and-kill stations. James et al. (2001) cited quality of food in the stations as a possible reason for the close-range failure of the system. They used fruit as a co-attractant and fresh fruit was added with the rotting fruit as necessary. Whereas, in our study, we used fermenting peach nectar in addition to ripening peaches as co-attractant, and this was replaced with new fruit and fermenting peach nectar every week. It is possible that the attract-and-kill stations used by James et al. (2001) with rotting fruit were not as effective as those used in our study. Further work is warranted to investigate the impact of the co-attractant and its quality on close-range stimuli for *Carpophilus* spp. to land on attract-and-kill stations.

The information on the effective drawing power of synthetic *Carpophilus* spp. pheromone is important. The results from our current study suggested that attract-and-kill stations placed at the north-west corner of a 1-ha block of stone fruit could give almost 100% protection from *Carpophilus* spp. up to at least 100 m.

Monitoring traps were of little importance for predicting the level of damage by *Carpophilus* spp. during the 2000/2001 season. The differences in fruit damage levels in control and treated blocks were very significant, but would not have been directly anticipated from the monitoring-trap catches because the populations indicated by the traps were not significantly different. At least the monitoring of trap catch data was indicating the fluctuations of *Carpophilus* spp. populations. For example, trap-catch data showed a sharp decline of *C. davidsoni* numbers in treated blocks (15 December, 2000) immediately after placement of attract-and-kill stations. The decline was not observed in the control blocks until the end of December, when growers sprayed insecticides against *Carpophilus* spp. The number of *C. davidsoni* started to increase dramatically in the control blocks after fruit harvest. This dramatic increase in trap catch might be caused by the higher level of residual *Carpophilus* spp. population in the control blocks compared to that in pheromone-treated blocks.

From this work we concluded that:

1. Attract-and-kill stations have the potential to replace insecticide sprays for the control of *Carpophilus* spp. in stone fruit.
2. Early deployment of attract-and-kill station is important.
3. A zone of *Carpophilus* spp. attraction of at least 1 ha radiating down-wind from concentrated sources of pheromones is possible.

Further work is required to determine the most effective co-attractant for use in the attract-and-kill station.

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